0·001 inch, according to the actual width of the slit), it is evident that the spectrum of the smallest objects can be examined. If some blood is in the field, it is easy to reduce the size of the image of the slit to dimensions covered by one blood-disk, and then, by pushing in the prisms, to obtain its spectrum.

If the object under examination will not transmit a fair image of the slit (if it be a rough crystal of jargoon for instance), it must be fixed in the universal holder beneath the slit and the light concentrated on it before it reaches the slit. If the spectra of opaque objects are required, they can also be obtained in the same way, the light being concentrated on them either by a parabolic reflector or by other appropriate means.

By replacing the illuminating lamp by a spirit-lamp burning with a soda-flame, and pushing in the spectrum-apparatus, the yellow sodium-line is seen beautifully sharp; and by narrowing the slit sufficiently it may even be doubled. Upon introducing lithium or thallium compounds into the flame, the characteristic crimson or green line is obtained; in fact so readily does this form of instrument adapt itself to the examination of flame-spectra, that for general work I have almost ceased to use a spectroscope of the ordinary form. The only disadvantage I find is an occasional deficiency of light; but by an improved arrangement of condensers I hope soon to overcome this difficulty.

V. "On some Optical Phenomena of Opals." By WILLIAM CROOKES, F.R.S. &c. Received April 23, 1869.

When a good fiery opal is examined in day-, sun-, or artificial light, it appears to emit vivid flashes of crimson, green, or blue light, according to the angle at which the incident light falls, and the relative position of the opal and the observer; for the direction of the path of the emitted beam bears no uniform proportion to the angle of the incident light. Examined more closely, the flashes of light are seen to proceed from planes or surfaces of irregular dimensions inside the stone, at different depths from the surface and at all angles to each other. Occasionally a plane emitting light of one colour overlaps a plane emitting light of another colour, the two colours becoming alternately visible upon slight variations of the angle of the stone; and sometimes a plane will be observed which emits crimson light at one end, changing to orange, yellow, green, &c., until the other end of the plane shines with a blue light, the whole forming a wonderfully beautiful solar spectrum in miniature. I need scarcely say that the colours are not due to the presence of any pigment, but are interference colours caused by minute striæ or fissures lying in different planes. By turning the opal round and observing it from different directions, it is generally possible to get a position in which it shows no colour whatever. Viewed by transmitted light, opals appear more or less deficient in transparency and have a slight greenish yellow or reddish tinge.

In order to better adapt them to the purposes of the jeweller, opals are almost always polished with rounded surfaces, back and front; but the flashes of coloured light are better seen and examined when the top and bottom of the gems are ground and polished flat and parallel.

A good opal is not injured by moderate heating in water, soaking in turpentine, or heating strongly in Canada balsam and mounting as a microscopic slide.

By the kindness of Mr. W. Chapman, of Frith Street, Soho, and other friends, I have been enabled to submit some thousands of opals to optical examination; and from these I have selected about a dozen which appeared worthy of further study.

If an opal which emits a fine broad crimson light is held in front of the slit of a spectroscope or spectrum-microscope, at the proper angle, the light is generally seen to be purely homogeneous, and all the spectrum that is visible is a brilliant luminous line or band, varying somewhat in width and more or less irregular in outline, but very sharp, and shining brightly on a perfectly black ground. If, now, the source of light is moved, so as to shine into the spectrum-apparatus *through* the opal, the above appearance is reversed, and we have a luminous spectrum with a jet-black band in the red, identical in position, form of outline, and sharpness with the luminous band previously observed. If instead of moving the first source of light (the one which gave the reflected luminous line in the red) another source of light be used for obtaining the spectrum, the two appearances, of a coloured line on a black ground, and a black line on a coloured ground, may be obtained simultaneously, and they will be seen to fit accurately.

Those parts of the opal which emit red light are therefore seen to be opaque to light of the same refrangibility as that which they emit; and upon examining in the same manner other opals which shine with green, yellow, or blue light, the same appearances are observed, showing that this rule holds good in these cases also. It is doubtless a general law, following of necessity the mode of production of the flashes of colour.

Having once satisfied myself that the above law held good in all the instances which came under my notice, I confined myself chiefly to the examination of the transmitted spectra, although the following descriptions will apply equally well, *mutatis mutandis*, to the reflected spectra. The examinations were made by means of the spectrum-microscope a description of which I have just had the honour of sending to the Society. This instrument is peculiarly adapted to examinations of this sort, both on account of the small size of the object which can be examined in it, and also as it permits the use of both eyes in viewing the spectrum.

The following is a brief description of some of the most curious transmission spectra shown by these opals. The accompanying figures, drawn with the camera lucida, convey as good an idea as possible of the different appearances. The exact description will of course only hold good for one

portion of the opal; but the general character of each individual stone is well marked.

No. 1 shows a single black band in the red. When properly in focus this has a spiral structure. Examined with both eyes it appears in decided relief, and the arrangement of light and shade is such as to produce a striking resemblance to a twisted column.

No 2. gives an irregular line in the orange. Viewed binocularly, this exhibits the spiral structure in a marked manner, the different depths and distances standing well out; upon turning the milled head of the stage-adjustment, so as to carry the opal slowly from left to right, the spiral line is seen to revolve and roll over, altering its shape and position in the spectrum. It is not easy to retain the conviction that one is looking merely at a band of deficient light in the spectrum, and not at a solid body, possessing dimensions and in actual motion.

No. 3 has a line between the yellow and green, vanishing to a point at the top, and near the bottom having a loop, in the centre of which the green appears. Higher up, in the green, is a broad green band, indistinct on one side and branching out in different parts.

No. 4 has a broad, indistinct, and sloping band in the blue, and another, still more indistinct, in the violet.

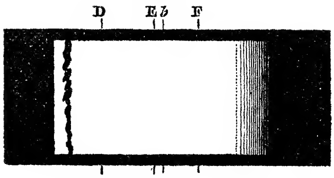
No. 5 has a band in the yellow, not very sharp on one side, and somewhat sloping. Upon moving the opal sideways, it moves about from one part of the yellow field to another. In one position it covers the line D, and is opaque to the sodium-flame of a spirit-lamp.

No. 6 shows a curiously shaped band in the red, very sharp and black, and terminating in one part at the line D. In the yellow there is a black dot. The spectrum of this opal showed by reflected light intensely bright red bands, of the shape of the transmission bands. On examining this opal with a power of 1 inch, in the ordinary manner, the portion giving this spectrum appeared to glow with intense red light, and was bounded with a tolerably definite outline. Without altering any other part of the microscope, the prisms were then pushed in so as to look at the whole surface of the opal through the prisms, but without the slit. The shape and appearance of the red patch were almost unaltered; and here and there over other parts of the opal were seen little patches of homogeneous light, which, not having been fanned out by the prisms, retained their original shape and appearance.

No. 7 shows a black patch in the red, only extending a little distance, and a line in the yellow. On moving the opal the line in the red vanishes, and the other line changes its position and form.

No. 8 shows the most striking example of a spiral rotating line which I have yet met with. On moving the opal sideways the line is seen to start from the red and roll over, like an irregularly shaped and somewhat hazy corkscrew, into the middle of the yellow. The drawing shows the appearance of this band in two positions.

No. 1.



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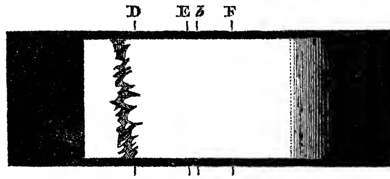

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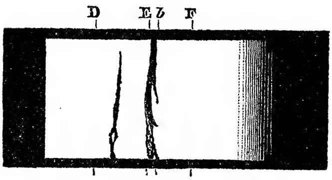

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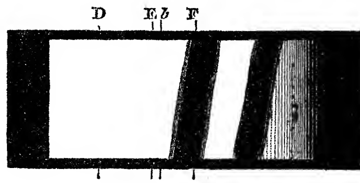

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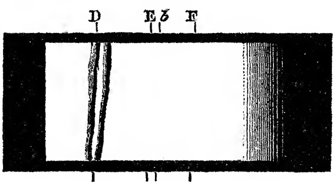

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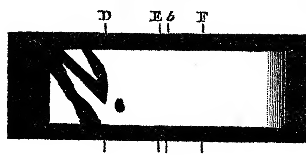

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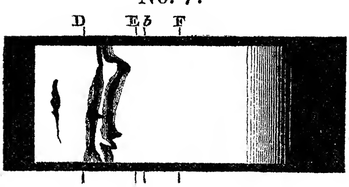

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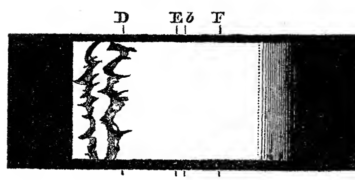

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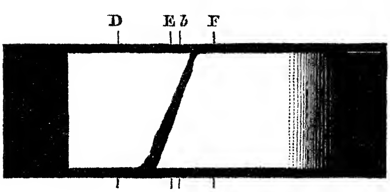

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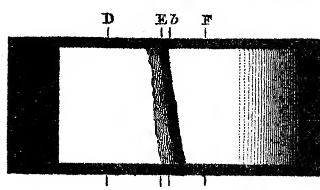
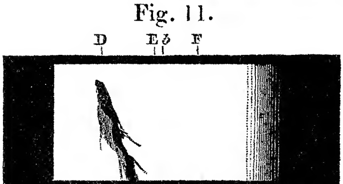


Fig. 11.



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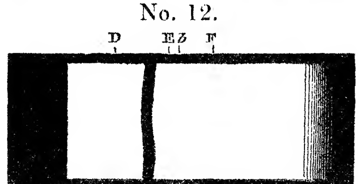

No. 9 is one of the most curious. A broad black and sharp band stretches diagonally across the green, touching the blue at the top and the yellow at the bottom.

No. 10 gives a diagonal band, wide, but straight, and tolerably sharp across the green. By rotating these opals, 9 and 10, in azimuth, whilst in the field of the instrument, the lines can be made to alter in inclination until they are seen to slope in the opposite direction.

No. 11 gives another illustration of a diagonal line, across the yellow and green, not extending quite to the top.

No. 12 is one of the best examples I have met with of a narrow, straight, and sharply cut line. It is in the green, and might easily be mistaken for an absorption-band caused by an unknown chemical element.

Other opals are exhibited which show a dark band travelling along the spectrum, almost from one end to the other, as the opal is moved sideways.

It is scarcely necessary to say that the colour of the moving luminous line varies with the part of the spectrum to which it belongs. The appearance of a luminous line, slowly moving across the black field of the instrument, and assuming in turn all the colours of the spectrum, is very beautiful.

All these black bands can be reversed, and changed into luminous bands, by illuminating the opal with reflected light. They are, however, more difficult to see; for the coloured light is only emitted at a particular angle, whilst the special opacity to the ray of the same refrangibility as the emitted ray holds good for all angles.

The explanation of the phenomena is probably as follows:—In the case of the moving line, the light-emitting plane in the opal is somewhat broad, and has the property of giving out at one end, along its whole height and for a width equal to the breadth of the band, say, red light; this merges gradually into a space emitting orange, and so on throughout the entire length of the spectrum, or through that portion of it which is traversed by the moving line in the instrument, the successive pencils (or rather ribbons) of emitted light passing through all degrees of refrangibility. It is evident that if this opal is slowly passed across the slit of the spectrum-microscope, the slit will be successively illuminated with light of gradually increasing refrangibility, and the appearance of a moving luminous line will be produced; and if transmitted light is used for illumination, the reversal of the phenomena will cause the production of a black line moving along a coloured field. A diagonal line will be produced if an opal of this character is examined in a sloping position.

The phenomenon of a spiral line in relief, rolling along as the opal is moved, is doubtless caused by modifying planes at different depths and connected by cross planes; I can form a mental picture of a structure which would produce this effect, but not clear enough to enable me to describe it in words.

It is probable that similar phenomena may be seen in many, if not all, bodies which reflect coloured light after the manner of opals. A magnificent specimen of Lumacelli, or Fiery Limestone, from Italy, kindly presented to me by my friend David Forbes, shows two sharp narrow and parallel bands in the red. I have also observed similar appearances in mother-of-pearl. The effects can be imitated to a certain extent by examining "Newton's rings," formed between two plates of glass, in the spectrum-instrument.

June 3, 1869.

The Annual Meeting for the election of Fellows was held this day.

Lieut.-General SABINE, President, in the Chair.

The Statutes relating to the election of Fellows having been read, Mr. Balfour Stewart and Dr. Maxwell Simpson were, with the consent of the Society, nominated Scrutators to assist the Secretaries in examining the lists.

The votes of the Fellows present having been collected, the following Candidates were declared to be duly elected into the Society.

Sir Samuel White Baker, M.A.
John J. Bigsby, M.D.
Charles Chambers, Esq.
William Esson, Esq., M.A.
Prof. George Carey Foster, B.A.
William W. Gull, M.D.
J. Norman Lockyer, Esq.
John Robinson M^cClean, Esq.
St. George Mivart, Esq.
John Russell Reynolds, M.D.
Vice-Admiral Sir Robert Spencer Robinson, K.C.B.
Major James Francis Tennant, R.E.
Prof. Wyville Thomson, LL.D.
Col. Henry Edward Landor Thuillier, R.A.
Edward Walker, Esq., M.A.

Thanks were voted to the Scrutators.

June 10, 1869.

Lieut.-General SABINE, President, in the Chair.

Dr. J. J. Bigsby, Prof. G. Carey Foster, Mr. J. R. M^cClean, Mr. St. George Mivart, and Dr. J. Russell Reynolds were admitted into the Society.

The following communications were read :—

I. "Researches on Gaseous Spectra in relation to the Physical Constitution of the Sun, Stars, and Nebulæ."—Second Note. By E. Frankland, F.R.S., and J. N. Lockyer. Received May 5, 1869.

We beg to lay before the Royal Society some further results of the researches on which we are engaged.

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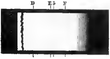

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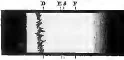

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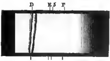

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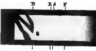

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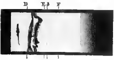

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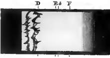

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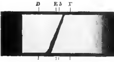

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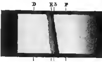
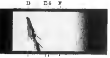


Fig. 11.



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